EFFECTS OF ARTIFICIAL DESTRATIFICATION ON THE ZOOPLANKTON OF HEART LAKE, ONTARIO

November, 1976

Ministry of the Environment
Ontario

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by

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November, 1976

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ABSTRACT

Heart Lake, a eutrophic body of water in Southern Ontario, was artificially destratified by aeration from June to September, 1975 and May to September, 1976 (the treatment year). Early summer crustacean zooplankton populations exhibited an increase as aeration began, probably resulting from oxygenation of previously anoxic bottom waters and subsequent downward expansion of zooplankton populations. No significant differences in mean zooplankton density (in no/m^3) between the control year (1968-69) and the treatment year could be found.

The zooplankton of Heart Lake indicated characteristically eutrophic conditions, with no clear change visible between control and treatment year indicator species. A large, new zooplankter, *Daphnia pulex*, appeared in 1976, replacing the smaller *D. rosea*, while the cold water-adapted *Cyclops bicuspidatus thomasii* was replaced by the warm water *Mesocyclops edax* and *Tropocyclops prasinus mexicanus* during the six year interval between the treatment and control years.

Aeration of Heart Lake bottom waters (previously anaerobic during summertime) has opened up a relatively predation-free habitat in this zone, resulting in the increased frequency of larger species of zooplankton (notably *D. pulex*). Consequently, an improved summertime food resource existed for planktivorous fish in the upper waters, as evidenced by examination of rainbow trout stomach contents, daphniid size decrease and daphniid helmet production. Additionally, increased algal filtering rates during 1976 by the greater numbers of larger sized zooplankton may have created some ecological selection for an algal species unaffected by zooplankton grazing, *Ceratium hirundinella*.

SUMMARY

Heart Lake, a small, eutrophic, recreational lake, located approximately 45 km. northwest of Toronto, was artificially destratified by means of aeration by the Ministry of the Environment on the decision of the Metro Toronto and Regional Conservation Authority. The lake had recently been experiencing nuisance summer blooms of blue-green algae and anoxic bottom waters, the latter stressing the sport fishery stocks. Destratification was begun on May 27, 1975, continued to November 25, 1975 and resumed on May 25, 1976. A 20-ℓ Schindler-Patalas trap was used for treatment year zooplankton sampling. The microcrustacea of these samples were identified and counted to the species level, with measurement of ovigerous *Daphnia* species. The invertebrate component of Heart Lake rainbow trout stomach contents was also identified and counted. Zooplankton data were expressed as densities (no/m^3) and percent abundances, being compared with control year data from Haney (1970) whenever possible.

Zooplankton densities ranged from $3.0 \times 10^5/m^3$ to $2.0 \times 10^3/m^3$ during the treatment year, with a mean of $9.9 \times 10^4/m^3$. Densities increased sharply just after the onset of artificial destratification in 1975, while 1976 spring zooplankton densities were similar to those of a year earlier, remaining seemingly unaffected by artificial destratification at this time. Densities of control and treatment years were not significantly different (Student's t-test, $p > .05$).

Heart Lake contained a greater number of species during the treatment year when compared to the control year. Thirteen herbivorous zooplankton species existed during 1975-76 as opposed to nine during 1968-69. One of the newly-found species, *Daphnia pulex*, became a dominant during 1976, replacing the smaller *D. rosea*. *Ceriodaphnia quadrangula*, found only during the control year, was replaced by *C. reticulata* during the treatment year. The reduced abundance of blue-green algae during 1975-76 may have caused a decrease in *Chydorus sphaericus* populations (a zooplankter commonly associated with blue-green blooms). *Cyclops bicuspidatus thomasii*, a cold water adapted cyclopoid common during the control year, was replaced by cyclopoids with seemingly warmwater affinities (*Mesocyclops edax* and *Tropocyclops prasinus mexicanus*) during the period between control and treatment years.

Heart Lake contained a species composition typical of eutrophic waters. No solid evidence existed for any change in lake trophy on the basis of species differences between control and treatment years, although some increase in grazing pressure was suggested by the increased numbers of large zooplankters in 1976.

It has been repeatedly shown that large Daphnia sp. are the preferred planktonic food source of rainbow trout. The sudden appearance of D. pulex during 1976 has therefore resulted in an improved food resource for rainbow trout in Heart Lake, as this was the largest zooplankter found in both control and treatment years. Examination of rainbow trout stomach contents confirmed that these fish were feeding on Daphnia populations during 1976. Additional evidence for this existed in a mean size decrease of Daphnia populations (as a result of trout eating only the largest individuals) and helmet production in D. galeata mendotae, also an important fish food organism.

The appearance of D. pulex can most probably be attributed to artificial destratification. As a result of previously anoxic bottom waters being oxygenated, a new habitat was made available to zooplankton populations in these strata. The low transparency of Heart Lake water (as found by Secchi disc measurements) created poorly illuminated conditions in the bottom waters, causing a probable reduction in predation pressure by fish (which visually seek out prey). Consequently, large zooplankters such as D. pulex, while being uniformly distributed throughout the strata of Heart Lake, could multiply without the limiting effect of fish predation in the bottom waters, allowing these populations to maintain themselves in spite of predation in the upper well-illuminated strata. Although the increase in Daphnia populations could also have been caused by a reduction in predation pressure as a result of diminished fish stocks, this seems unlikely as rainbow trout continued to be stocked annually in Heart Lake with resident populations of catfish, bass, trout and minnow species present at all times.

The increased numbers of large herbivorous zooplankters in Heart Lake during 1976 would most probably result in increased grazing pressure on edible phytoplankton populations. A non-grazeable algal species

(Ceratium hirundinella) became extremely abundant in 1976, possibly as a result of gaining an ecological advantage over competing algal species due to its resistance to zooplankton grazing pressure.

PREFACE

Artificial lake destratification by means of aeration is rapidly becoming a common aquatic management technique. While the effects of destratification on water chemistry are fairly well known, documented effects on the lake biota are relatively scarce (Fast 1971a, 1971b; Lackey 1973). Although the primary objectives of any artificial destratification project may not include control of zooplankton populations, knowledge of the effects of such treatment is important. Zooplankton form a connecting link in the food chain between phytoplankton populations and the fishery of a lake. Any effects of destratification on the zooplankton population may result in repercussions to other trophic levels. As the mechanisms governing these repercussions are not always well understood, documented accounts of any changes to zooplankton populations, as well as other lake biota, are necessary if the biological effects of lake aeration are to be predicted with any degree of reliability.

Heart Lake, a small (17.5 ha.) eutrophic lake, located 45 km. northwest of Toronto is currently used for high intensity summer recreation. Recent blooms of blue-green algae have degraded swimming areas and the largemouth bass/rainbow trout fishery of the lake has been frequently stressed by anoxic conditions in the bottom waters. It was decided by the Metro Toronto and Regional Conservation Authority that artificial destratification through aeration would improve Heart Lake recreationally by reducing or eliminating the above problems. As a result, aeration began in June, 1975 with the cooperation of the Ontario Ministry of Natural Resources and the Ontario Ministry of the Environment. The purpose of this report is to describe effects of the above on the zooplankton populations of Heart Lake, with some reference to the phytoplankton population and the fishery.

METHODS AND MATERIALS

Historical information on Heart Lake and zooplankton populations was obtained from Haney (1970) and used as "control year" data (1968-1969). Sampling during the artificial destratification "treatment year" began on May 27, 1975, continued to November 25, 1975 and resumed on May 25, 1976. Zooplankton samples were taken bi-weekly with a 20-litre Schindler-Patalas trap (80 micron mesh) at the surface and at 3 meter depth intervals. In order to avoid the stronger aerator currents (and their effects on zooplankton distribution), the sampling station was located approximately 100 meters away from the destratification upwelling. Prior to 1976, samples were preserved in 5% formalin and thereafter in 5% sugar formalin, as outlined in Haney and Hall (1972).

In the laboratory, the crustacean zooplankton were enumerated and identified to species (Edmondson 1959, Brooks 1957). All taxa were counted from May 27, 1975 to May 25, 1976, after which only Daphnia spp. were examined. The latter continued to be counted until August 19, 1976. Additionally, Daphnia spp. measurements (to the nearest 0.1 mm) were taken from the centre of the eye to the base of the shell spine (Fig. 6), for mature, ovigerous females only. By this method, Daphnia helmets (Fig. 6), whenever present, were left unmeasured. These structures are extremely variable in length and do not grow in proportion to the rest of the body (Brooks 1965; Dodson 1974; Jacobs 1966). This methodology is consistant with that of Hrbacek and Hrbackova-Esslova (1960) who found it necessary to correct for helmet length in order to determine accurate growth rates and body lengths of Daphnia spp.

Stomach contents were identified from several rainbow trout obtained from Heart Lake (one angled directly from the pelagic zone - July 5, 1976) on two separate dates. Ingested Daphnia were measured whenever possible.

Results were expressed as density (numbers per cubic meter) and percentage abundance. For whole-lake density values, data were volumetrically corrected for each sampling stratum by multiplying by a factor determined by the percentage of the total lake volume occupied by that stratum. Data

to be used to illustrate depth distribution in the water column were not volumetrically corrected. Densities to be compared with historical sources of "control" data (Haney 1970) were treated so that both sets were compatible in methodology (during the control year, only 0-6 m strata were sampled, uncorrected volumetrically and naupliar counts were not performed). Mean densities for the control and treatment years were calculated, excluding the months not sampled in the 1975-76 year in the control year calculations.

RESULTS AND DISCUSSION

Zooplankton Density

Volumetrically corrected zooplankton densities ranged from 3.0 x $10^5/m^3$ in November, 1975 to 2.0 x $10^3/m^3$ in March, 1976 (Fig. 1). As intermittent aeration in Heart Lake did not begin until June 25 (with continuous operation beginning on July 30), there is some evidence for a naturally occurring pre-destratification spring peak in May, 1975 or earlier. Densities dropped toward the end of June, and then began to increase sharply during July. This increase corresponds to the onset of destratification and increased depth distribution (Fig. 6). During September, October and early November, zooplankton populations declined somewhat, after which highest densities were attained during late November. The 1976 data show a rise from very low concentrations of zooplankton in March to a low spring peak found in May, 1976. Both spring densities for these years indicate negligible effects of destratification on zooplankton density at this time of year.

As control year data were treated quite differently from that of the treatment year, any density comparisons made between both sets of data would be unreliable. However, a rough comparison may be made by modifying 1975-76 data to match Haney's methodology (naupliar counts and volumetric corrections omitted, nine-meter stratum not included). Mean densities, for control and treatment years respectively, were 1.54 x $10^5/m^3$ and 0.99 x $10^5/m^3$. Statistical examination (Student's t-test, $p > 0.05$) revealed the zooplankton densities compared in the above fashion to be insignificantly different.

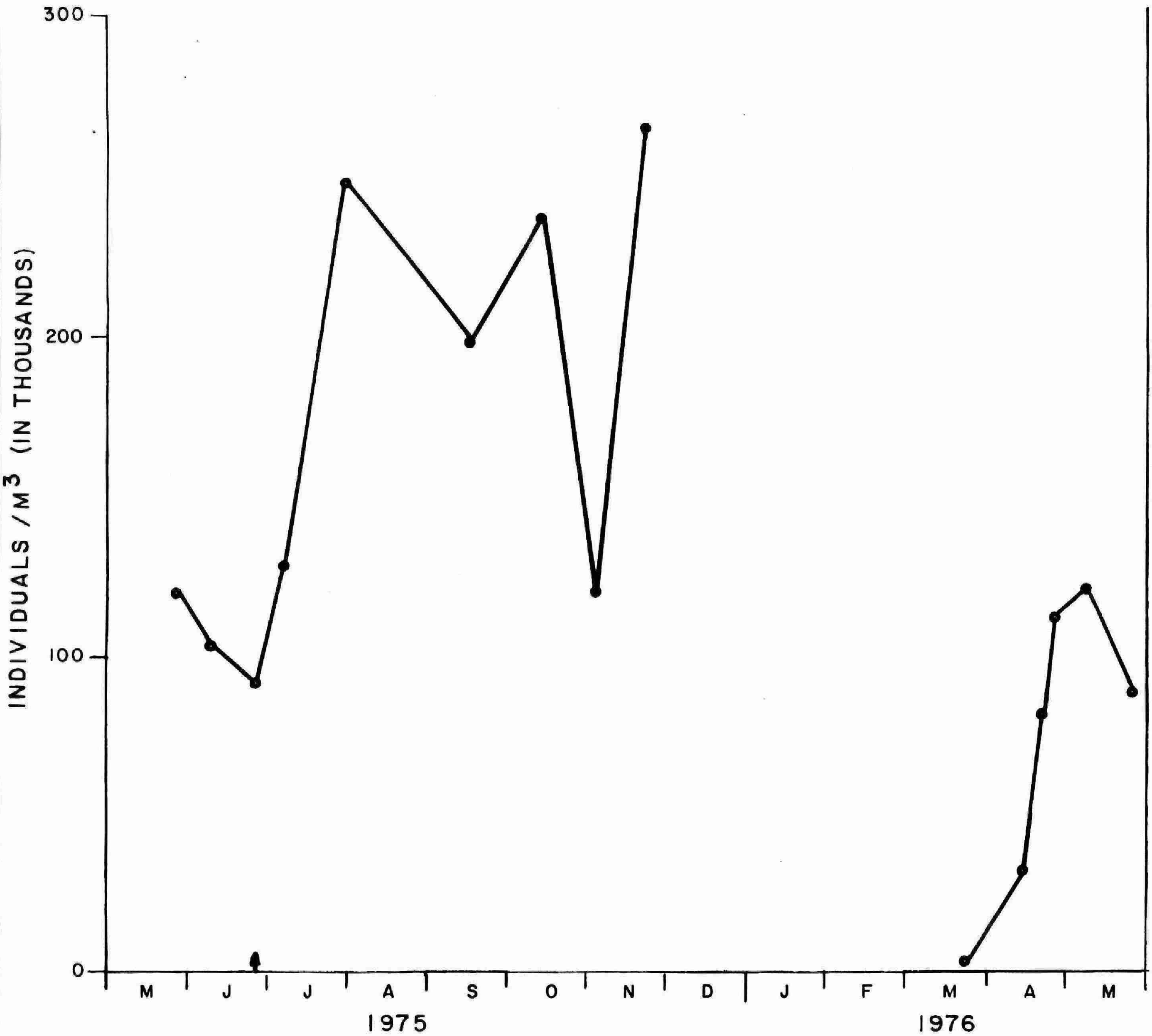

Figure 1: Volumetrically corrected (whole-lake) mean zooplankton densities, Heart Lake, 1975-1976. Arrow corresponds to the onset of artificial destratification.

Table 1: Species presence lists: control (1968-69) and treatment years (1975-76) in Heart Lake.

1968-69	1975-76
Calanoida:	Calanoida:
Diaptomus oregonensis Lilljeborg	*Diaptomus oregonensis* Lilljeborg
Cyclopoida:	Cyclopoida:
Cyclops bicuspidatus thomasii S.A. Forbes	*Mesocyclops edax* S.A. Forbes
	Tropocyclops prasinus mexicanus Kiefer
	Eucyclops speratus Lilljeborg
	Eucyclops agilis Koch
Cladocera:	Cladocera:
Daphnia galeata mendotae Birge	*Daphnia galeata mendotae* Birge
Daphnia rosea Sars.	*Daphnia rosea* Sars.
Daphnia parvula Fordyce	*Daphnia pulex* Leydig
Daphnia catawba Coker*	*Daphnia catawba* Coker*
Ceriodaphnia quadrangula O.F. Muller	*Daphnia parvula* Fordyce*
Bosmina longirostris O.F. Muller	*Daphnia ambigua* Scourfield*
Chydorus sphaericus O.F. Muller	*Daphnia retrocurva* Forbes*
Diaphanosoma brachyurum Lievin	*Ceriodaphnia reticulata* Jurine
	Ceriodaphnia lacustris Birge
	Bosmina longirostris O.F. Muller
	Chydorus sphaericus O.F. Muller
	Diaphanosoma leuchtenbergianum Fischer
	Alona sp+
Chaoborus sp.	*Chaoborus* sp
	Harpacticoid sp+
	Ostracod sp+

* indicates a rare species

\+ indicates an organism usually found in benthic or littoral areas - not planktonic

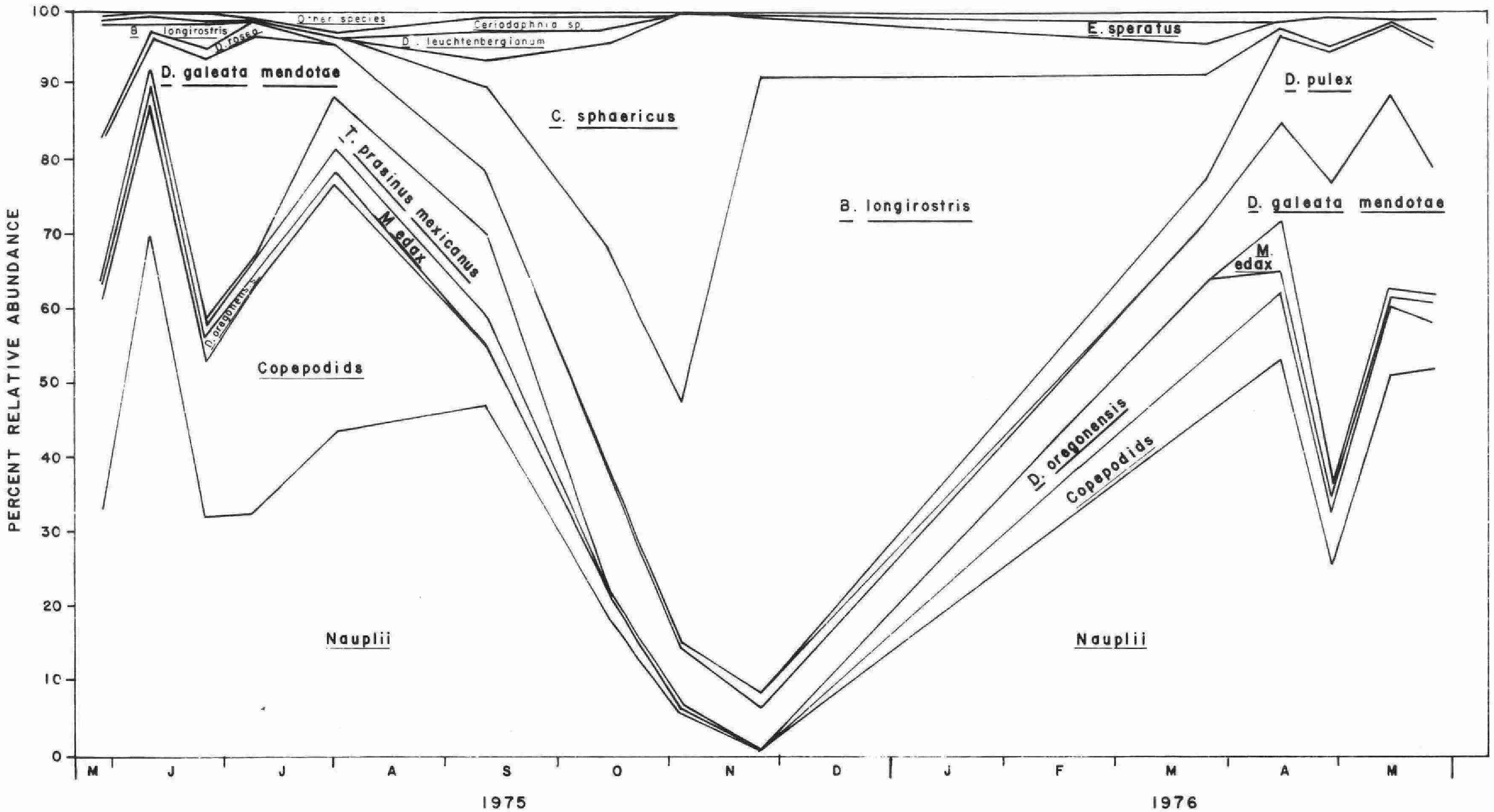

FIGURE 2: RELATIVE ABUNDANCES OF ZOOPLANKTON SPECIES DURING THE TREATMENT YEAR (1975 - 1976) IN HEART LAKE, ONTARIO.

Species Composition

Heart Lake, in the 1975-76 treatment year, contained a greater number of species than in the control year. As the control year study concentrated primarily on herbivorous zooplankton, cyclopoid copepod species (predators) were grouped under one species (Haney 1970). A comparison between control and treatment years indicated thirteen herbivorous species during 1975-76 as opposed to only nine in 1968-69 (Table 1). Three of the four newly-found species were very rare, but the fourth species, Daphnia pulex became a dominant in 1976.

(a) Copepoda

Immature copepods (nauplii and copepodids) frequently comprised 50% or more of the total zooplankton numbers during the treatment year. It is possible to trace the succession of stages in the life cycle (nauplius to copepodid to adult) in Fig. 2 by following the abundance peaks from June to September, 1975.

Only one calanoid copepod was found in Heart Lake during both study years - Diaptomus oregonensis. This species exhibited a greater numerical density maximum in the control year (as did the total zooplankton density of that year), being three times less abundant in the treatment year. Patalas (1971) found D. oregonensis to tend towards small shallow lakes in the E.L.A. (Experimental Lakes Area of northwestern Ontario) of <100 ha. area, <20m deep, with low transparency - <7m Secchi disc. Heart Lake fits this category well. Rigler and Langford (1971 In Patalas 1971) found this species common to 69% of southern Ontario lakes, while in the E.L.A. it was limited to 40% of the lakes. D. oregonensis, therefore, is a calanoid species typical of many Ontario lakes.

Patalas (1972) found oligotrophic areas in the Great Lakes to support more calanoid copepod species than eutrophic areas, as did McNaught (1975). The presence of only one such species in Heart Lake therefore suggests a state of eutrophy.

All cyclopoid copepods were grouped under the dominant cyclopoid species (*Cyclops bicuspidatus* thomasii) in the control year. As a result, it is not known whether any additional cyclopoid species existed at this time. However, the large numbers of *C. bicuspidatus thomasii* present during 1968-69 and the complete absence of this species in the treatment year does show a major change in the cyclopoid composition between both studies. As this species was not present during May or June of 1975 (before aeration) and was common on the corresponding dates in 1968, it is probable that artificial destratification did not cause the disappearance of this zooplankter. The elimination of *C. bicuspidatus thomasii* must therefore have occurred in the natural successional pattern of the lake. The dominant cyclopoids *Mesocyclops edax* and *Tropocyclops prasinus mexicanus* seem to have replaced it as planktonic predators, although in smaller total numbers.

As cyclopoids are mostly predatory species, feeding on smaller zooplankters, corelation with any trophic change is difficult (McNaught 1975). Rather, a change in the temperature regime of Heart Lake seems to have been the controlling factor in the above species shift. *C. bicuspidatus thomasii* has been found most abundant in deep, transparent and presumably colder waters, as well as becoming seasonally most abundant during spring when lakes are cold. *Mesocyclops edax* and *T. prasinus mexicanus*, on the other hand, prefer smaller, shallow, less transparent waters (presumably warmer), as well as warmer times of the year (Patalas 1971, 1972; McNaught et al 1975). Carter (1971) found *M. edax* to succeed *C. bicuspidatus thomasii* during warm water summertime conditions in a number of ponds near Georgian Bay. The former was never abundant in Georgian Bay, which was characteristically colder.

As *C. bicuspidatus thomasii* does seem to be cold water adapted it is logical to assume that during summertime it would frequent the coldest water in HeartLake. On the other hand, the coldest waters were frequently anaerobic during the control year, and would preclude this organism (Haney 1970). Comparison of the

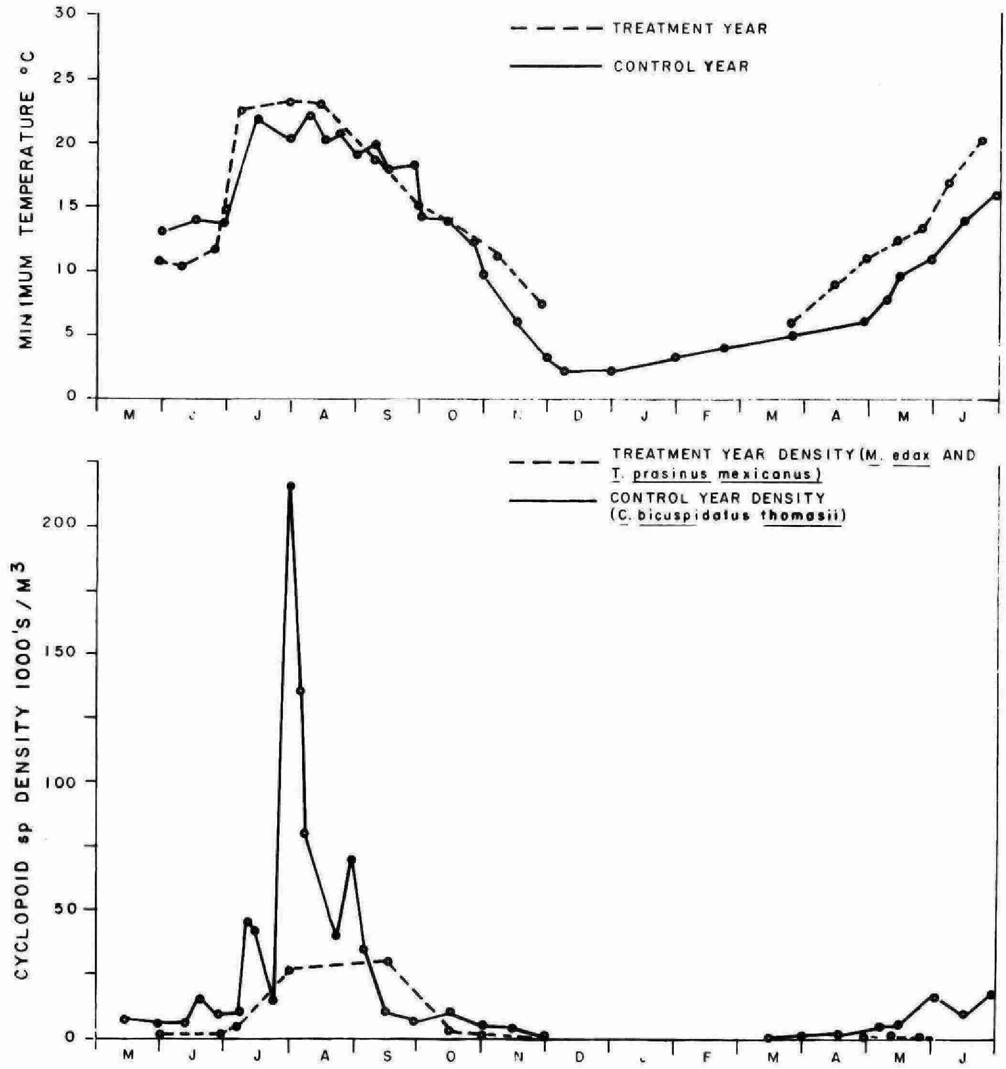

FIGURE 3 : MINIMUM WATER TEMPERATURES OF AEROBIC STRATA IN HEART LAKE, ONTARIO, AND CYCLOPOID COPEPOD DENSITIES DURING TREATMENT AND CONTROL YEARS

minimum water temperature in the aerobic zone during control and treatment years (Fig. 3) shows that such areas have increased in temperature during the spring and summer seasons of 1975-76. Although the increase in minimum temperature would certainly not improve the chances of C. bicuspidatus thomasii repopulating the lake, artificial destratification cannot be held reponsible for eliminating this species, as it had disappeared before such treatment had started.

(b) Cladocera

Cladocera were the most important adult group, in both the control year (eight species present, one of which was rare) and the treatment year (13 species, five of which were rare), (Table 1). Daphnia were the most important spring organisms in 1975-76, presumably grazing heavily upon the phytoplankton populations at this time, while Bosmina and Chydorus were the most abundant genera in the late summer, fall and winter. All cladocerans present were strictly herbivorous.

In both the control and treatment years, Daphnia galeata mendotae exhibited the greatest numerical importance among the Daphnia species. Dicyclic fluctuations were evident in its seasonal abundance pattern. A strong June and July maximum was followed by a weaker fall peak in 1968-69 and 1975. In 1976, however, the June-July maximum may have occurred earlier (in April and May), possibly as a result of the earlier onset of aeration, with higher densities than in 1975. D. galeata mendotae was found by Patalas (1972) to be more common in Lake Erie (eutrophic and mesotrophic status) than in the other Great Lakes (of more oligotrophic and mesotrophic status).

Daphnia rosea was the dominant daphniid in Heart Lake during 1964 (Burns 1965, In Haney 1970). In 1968-69 its status was reduced to second dominant daphniid, and in 1975 the D. rosea populations were reduced tenfold from the control year. This species disappeared entirely in 1976, when destratification was in effect. D. rosea seems to have been replaced by D. galeata mendotae and the larger D. pulex in 1976 (the latter was never found in Heart Lake before late fall, 1975). Although measurements of D. rosea were not taken in the present study, Brooks (1957) describes this species as smaller than the other two. It is possible that the larger size and consequently more efficient filtering rate of D. pulex and

D. galeata mendotae (Allan 1974; Brooks and Dodson 1965) may have left D. rosea at a competitive disadvantage, causing its population to be reduced and finally eliminated.

Daphnia parvula was common during the control year, but was very rare during the treatment year. It is possible that this daphniid went the way of D. rosea, being out-competed for algal food as a result of its small size (Brooks 1957) by the larger D. pulex and D. galeata mendotae.

D. catawba, D. ambigua and D. retrocurva were all very rare species in the 1975-76 Heart Lake zooplankton. While D. catawba was also rare during the control year, the other two species were never found at this time.

The Ceriodaphnia genus exhibited a tenfold decrease in mean density between the treatment and control years. A change in the species composition also occurred. While only C. quadrangula was found in 1968-69, both C. reticulata and C. lacustris were present during 1975-76. Again, the appearance of the larger C. reticulata represents a shift to a more efficient filter feeder.

Diaphanosoma, on the other hand, doubled its numbers in the treatment year, being present only during the fall in both study years. D. leuchtenbergianum was found during the treatment year, while D. brachyurum existed only during the control year. Some taxonomic difficulty does exist within this genus. Brooks (1959, In Edmondson 1959) states that the above are probably the same species, but different varieties. Davis (1969) found D. leuchtenbergianum to be confined to the eutrophic western basin in Lake Erie.

Bosmina longirostris attained a slightly greater maximum density during the treatment year, but was lower in mean numerical abundance at this time, when compared to that of the control year. It was the most important zooplankter during late November, 1975 and the 1975-76 winter. During the control year, it was dominant only during October and November. McNaught et al (1975) found it to occupy the most eutrophic part of Lake Ontario, while Andersson et al (1973) state it to be the second dominant zooplankter (after Chydorus sphaericus) in the eutrophic Lake Trummen. B. longirostris becomes

more common in eutrophic waters (Frey 1964), replacing Eubosmina coregoni as the degree of eutrophication increases (Deevey 1941; In Brooks 1969). The latter organism has never been found in Heart Lake.

Similarly, abundant Chydorus sphaericus populations also seem to indicate eutrophic conditions (Brooks 1969; Andersson et al 1973; Watson and Carpenter 1974). This organism seems to become numerous whenever blue-green algae blooms are evident (Frey 1960, 1969). Its reduced abundance during the treatment year may be related to decreased populations of blue-greens (especially during 1976) as a result of aeration (K. Nicholls, Ministry of the Environment, personal communication). C. sphaericus was the dominant zooplankter during late October and early November of 1975, overwintering as a second dominant with B. longirostris.

Chaoborus sp., (a midge larva) was present in both the control and treatment years. Being an important source of pelagic trout food (Fast 1971b), this organism did not seem to be numerically affected by destratification.

In summary, Heart Lake contains a species composition characteristic of eutrophic lakes. The presence of only one calanoid species, as opposed to thirteen Cladoceran species (several of which are characteristic of eutrophic waters) lends support to the above. Conflicting evidence of changes in Heart Lake trophy between control and treatment years is present. Although an increase of D. leuchtenbergianum (a eutrophic organism) has occurred, other eutrophic species have declined (B. longirostris, C. sphaericus). The grazing pressure of the zooplankton population seems to have increased, however, as larger zooplankters have appeared (D. pulex, C. reticulata) at the expense of smaller zooplankters with lower filtering rates, notably during the spring of 1976. Greater species diversity was also found in Heart Lake following artificial destratification.

Zooplankton, Phytoplankton and the Fish Population

The treatment year Heart Lake fish population included brown bullheads (Ictalurus nebulosus), largemouth bass (Micropterus salmoides). rainbow trout (Salmo gairdneri), white suckers (Catostomus commersoni), bluntnose minnows (Pimephales notatus) and fathead minnows (Pimephales promelas). The first three species constitute the sport fishery of Heart Lake. Rainbow

trout occupy the pelagic zone during sommertime conditions (Stocek and McCrimmon 1965) and therefore must utilize pelagic food resources. Rainbow trout fingerlings (about 12 cm. long) are stocked annually in Heart Lake at the beginning of the angling season (B. Hester, Ministry of Natural Resources, personal communication).

Most freshwater fish are facultative planktivores at some point in their lives (Brooks 1969), with selective visual predation being exhibited by most species. Cladocera, followed by cyclopoids and calanoids (in that order) are preferred as food (Brooks 1968, 1969). As the most easily seen zooplankters are eaten first (Zaret 1975), frequently large individuals comprise the bulk of the fish stomach contents. Galbraith (1962) found that rainbow trout preferred large Daphnia (>1.3 mm long) over smaller individuals. However, visibility, and not only physical size, is the controlling factor in visual prey selection - a small pigmented zooplankter will be seen (and eaten) more easily than a large transparent individual. As the pigmented eye is the most readily visible part of most Cladocerans, it follows that individuals with large eyes will likewise be eaten first (Zaret 1972).

Rainbow trout, being at times planktonic fish in Heart Lake, have been shown to prefer large Daphnia to any other zooplankton (Galbraith 1962; Brooks 1969). In Heart Lake, two species of Daphnia dominate during the treatment year - D. galeata mendotae (during 1975 and 1976) and D. pulex (during 1976 only). The latter is much larger as well as having a more obvious eye-spot (Fig. 5). These characteristics should increase the susceptibility of D. pulex with respect to rainbow trout predation, as outlined above.

Measurement of D. pulex and D. galeata mendotae individuals revealed a decrease in the mean length of both species during 1976, although the size reduction was much more apparent in D. pulex (Fig. 4). The greatest size reduction in this species occurred in a population decrease just after May 25, 1976, when there were few adult D. pulex found. This date represents the interval between two peaks of the adult population numbers, as mostly immature individuals were present in the sample. As these younger daphniids became adults during later sampling dates, it is clear that they matured at a smaller size (Fig. 4). This can be seen as an effect of predation. Other workers have found similar effects on Daphnia populations. Hrbacek and Hrbackova-Esslova (1960) found a diminished mean length in several Daphnia species when exposed to higher intensities of fish predation. Archibald (1975) noticed the minimum egg bearing size of D. pulex was also smaller with

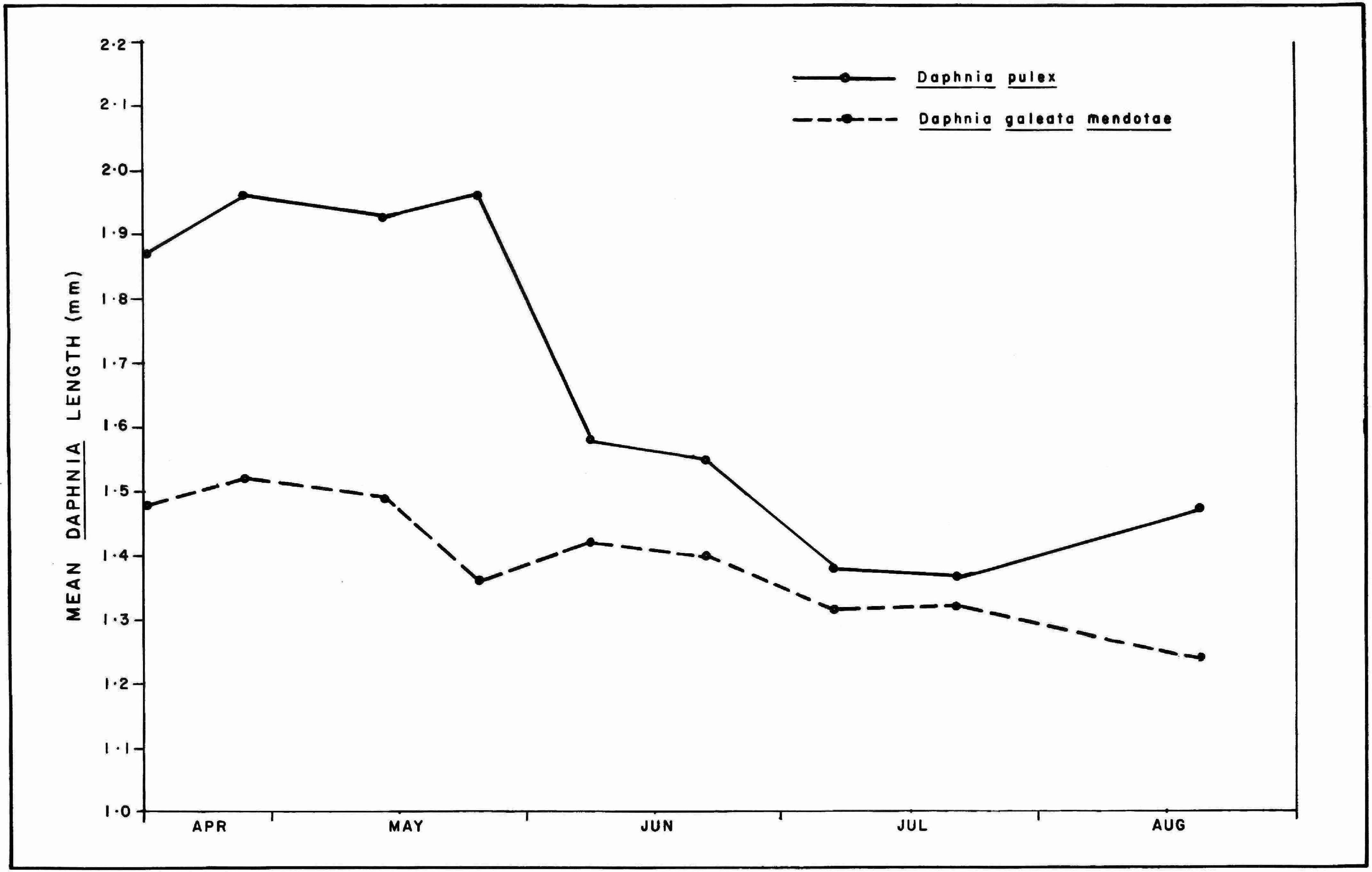

FIGURE 4: DECREASE IN MEAN LENGTH OF DAPHNIA POPULATION OF HEART LAKE, 1976.

Table 2: Stomach contents of three 25-26 cm. rainbow trout (*Salmo gairdneri*), Heart Lake, 1976.

Food Item	Numbers July 5	August 18	August 18
Limnetic			
Cladocera			
Daphniidae			
D. pulex	61	19	1
D. galeata mendotae	2	5	
damaged *Daphnia*	16		
Bosminidae			
Bosmina longirostris	1	4	
Copepoda			
Cyclopoida			
M. edax		6	
Diptera			
Chaoborinae			
Chaoborus sp.	2	2	1
Benthic and Littoral:			
Cladocera			
Chydoridae			
Leydigia quadrangularis		1	
damaged chydorids		1	
Oligochaeta	1		
Hydracarina	1	2	
Culicinae		2	1
Tendipedidae (Chironomidae)	1	1	
Corixidae			1

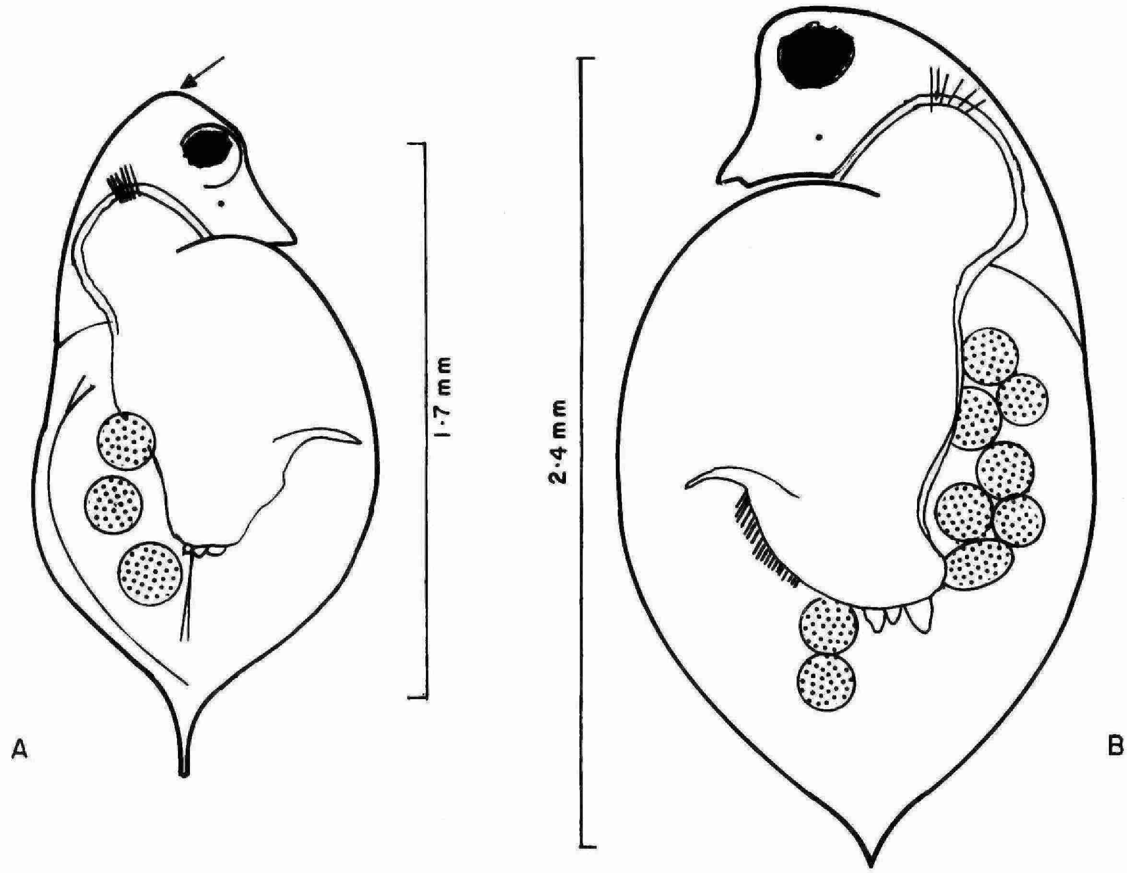

FIGURE 5: TRACINGS FROM PHOTOGRAPHS OF (A) Daphnia galeata mendotae AND (B) Daphnia pulex FROM HEART LAKE, 1976. CENTRE OF EYE TO BASE OF TAIL SPINE MEASUREMENTS ARE SHOWN, AS WELL AS THE LARGER EYE OF D. pulex. A LOW HELMET CAN BE SEEN ON D. galeata mendotae (INDICATED BY ARROW).

increased fish predation. This decrease in mean size of D. pulex adults, therefore suggests considerable visual predation on their numbers.

Examination of Heart Lake rainbow trout stomachs confirmed the above. D. pulex, and to a lesser extent, D. galeata mendotae were important food sources for planktonic rainbow trout. On July 5, 1976, in stomach contents of a rainbow trout angled from the pelagic zone of Heart Lake, D. pulex outnumbered any other food organism by a ratio of more than 30 to 1 (Table 2). Moreover, measurements taken on these indicated that the trout were selectively feeding on the very largest individuals available, as the sizes recorded were much larger than those ever found in zooplankton trap samplings. By August 18, 1976 the importance of D. pulex as trout food had decreased somewhat, as the proportion of this organism was lower in the total stomach contents (Table 2). Other zooplankters (M. edax, D. galeata mendotae) were by then being eaten more frequently, as their size approximated the smaller size of D. pulex then present in the lake. Measurements of ingested D. pulex indicated a mean length almost identical with those of trap samplings on the same date - larger sized D. pulex were either absent or very rare, as even trout could not find and eat them. By and large, analysis of rainbow trout stomach contents revealed a mainly pelagic food source at the time of capture, as most of the ingested organisms found were characteristically open water species (Table 2).

Helmet size was observed to increase in D. galeata mendotae (Fig. 5) through 1976, becoming most pronounced during August. Several authors have linked an increase in helmet length with an increase in visual predation. Experiments in guppy predation on Daphnia galeata mendotae revealed high-helmeted forms to survive predation more effectively than low-helmeted forms (Jacobs 1966). Brooks (1968) states that a diversion of growth energy into helmet production reduces the visible length of the daphniid as the more opaque body becomes smaller. The helmet, being a thin, transparent structure, is invisible in the water and cannot be seen by fish. As a result, a smaller visible body size is produced with less visibility to fish (and consequently less predation). Such individuals would be selected for and become common in the population. The increase in helmet size of D. galeata mendotae in Heart Lake therefore further supports previous findings that Daphnia are an important food resource for rainbow trout in the lake.

The sudden appearance of D. pulex during 1976 and its absence during previous years in Heart Lake can be attributed to the effects of artificial destratification, as well as to differences in rainbow trout predation.

Haney (1970) found that Heart Lake summertime zooplankton populations during 1968-69 were restricted to the epilimnion (1 mg/l oxygen concentration), as a result of anoxia in the hypolimnion. During May and early July, 1975, before continuous aeration was established, zooplankton populations also exhibited reduced densities at the six and nine meter strata. This can be attributed to limiting oxygen concentrations at these depths (Fig. 6).

With the beginning of thorough aeration at the end of July 1975, oxygen levels in the bottom waters were increased along with the hypolimnetic zooplankton populations (Fig. 6). Fast (1971a, 1971b) found similar occurrences in El Capitan Reservoir and in Hemlock Lake. In both cases, the previously anoxic hypolimnia became capable of supporting extensive zooplankton populations. Both lakes exhibited an increase in whole-lake population density (notably an 88-fold increase in D. pulex in Hemlock Lake), as a result of the additional habitat created by aeration of the bottom waters.

The extension of such populations into the poorly illuminated depths of Heart Lake opened up a relatively predation-free habitat, as it is likely that insufficient light existed in the bottom waters for visual predators (such as rainbow trout) to feed effectively (Fast 1971b; McLaren 1963). Secchi disc values, after bottom waters become oxygenated, ranged from 0.6m to 4.1m with a mean value of 2.0m.

In pre-aeration situations, any D. pulex individuals would have been subjected to considerable predation pressure as a result of being limited to the illuminated surface waters. This could explain their absence at this time. The onset of artificial destratification, however, allowed D. pulex to colonize and multiply in the dark depths with much less predation pressure in this zone. Their greater inherent size made for more efficient grazing capability (Allen 1974; Brooks and Dodson 1965) than that of D. rosea or D. galeata mendotae and eventually resulted in the dominance of D. pulex during 1976. Ongoing predation in the shallow depths caused a gradual size decrease in both species from the initial spring population, but the availability of relatively predation-free habitat allowed the population to maintain itself. The new balance struck between competition for food and predation pressure between D. galeata mendotae and D. pulex has been primarily an effect of increased depth distribution as a result of aeration of bottom waters.

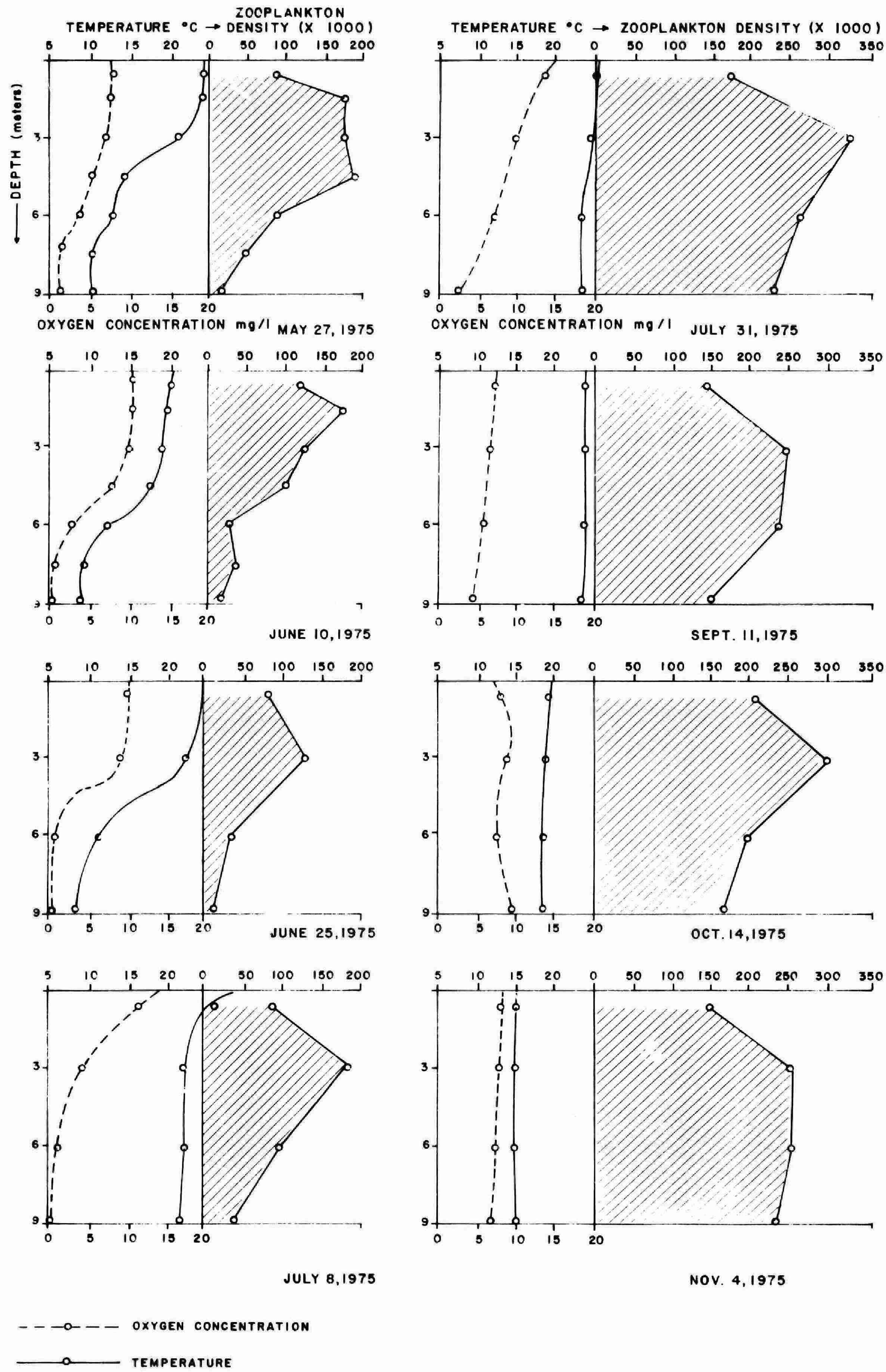

FIGURE 6 : ZOOPLANKTON DEPTH DISTRIBUTION WITH RESPECT TO OXYGEN AND TEMPERATURE PROFILES IN HEART LAKE, 1975. DENSITIES IN no./m^3

The increased populations of large zooplankters in Heart Lake during the treatment year could conceivably have been caused by a decrease in predation pressure, if any reduction in fish populations had taken place. However, this possibility seems unlikely as trout fingerlings have been stocked annually in Heart Lake, with a resident trout and bass population present at all times (B. Hester, Ministry of Natural Resources, personal communication). Additionally, evidence of fish populations exists as a result of predation effects on zooplankton (discussed above). Availability of predation-free bottom-water habitat as a result of artificial destratification therefore seems to be a more likely explanation for the appearance of larger species of zooplankton.

Although the artificial destratification of Heart Lake has had a direct effect upon its phytoplankton community in that blue-green algal populations have been reduced (K. Nicholls, Ministry of the Environment, personal communication), there have also been indirect effects on algal populations as a result of changes occurring in the zooplankton community (notably the increased frequency of large zooplankters).

According to Brooks and Dodsons' (1965) size efficiency hypothesis, larger zooplankters would be more efficient at filtering out phytoplankton. The increased frequency of large grazing zooplankters (<u>D. pulex</u>, <u>D. galeata mendotae</u>, <u>C. reticulata</u>) at the expense of smaller zooplankters after the onset of artificial destratification would, in all probability, increase the grazing pressure in Heart Lake. Although precise grazing rates cannot be calculated due to the extreme variability possible, it is most likely that grazing pressure increased rather than decreased in the control year.

This increased grazing pressure during 1976 has possibly affected the species composition of Heart Lake. An armoured dinoflagellate, <u>Ceratium hirundinella</u> attained extremely high densities during the summer, to the virtual exclusion of other species of algae (K. Nicholls, Ministry of the Environment, personal communication). As dinoflagellates have been shown to be relatively unaffected by zooplankton grazing (Porter 1973; Hargrave and Geen 1970), it is possible that the increased grazing pressure during 1976 may have selected against species of phytoplankton other than dinoflagellates and selected for the non-grazable <u>Ceratium hirundinella</u>.

This could have contributed to the large blooms of *Ceratium* at this time. A collapse of this algal population led to anoxic conditions and a fish kill during August in Heart Lake. It is noteworthy that the populations of *Daphnia* contributed much of the grazing pressure prior to the *Ceratium* bloom in 1976 (Figure 2).

On August 18, 1976, *D. pulex* individuals were found to be pink in colour. The extremely low oxygen concentrations at this time prompted this organism to produce hemoglobin (pink in colour) in order to increase oxygen uptake from the surrounding water (Fox 1948).

The probable absence of rainbow trout stocks in Heart Lake after the August fish kill would in all likelihood favour increased future populations of *D. pulex*, as predation on such populations would have decreased greatly. These in turn would most probably create additional selection for *Ceratium* blooms with the possibility of future collapses and oxygen depletions. It is therefore recommended that the current annual rainbow trout stocking programme be continued, realizing that remedial measures to control the *Ceratium* populations are available (Nicholls and Kennedy, 1976).

In conclusion, it should be emphasized that prior to the unexpected collapse of the dinoflagellate bloom and resultant depletion of dissolved oxygen, artificial destratification and aeration of Heart Lake resulted in a more suitable habitat for fish and fish food organisms than that which had characterized the lake in recent years.

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